

(12)

(21) 2 414 138

(22) 13.06.2002

(51) Int. Cl. 7: **C22C 38/04, C21D 8/02,  
C22C 38/06**

(85) 02.12.2002

(86) PCT/EP02/06480

(87) WO02/101109

(30) 101 28 544.2 DE 13.06.2001

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(54) ACIER ET FEUILLARD OU TOLE D'ACIER A RESISTANCE TRES ELEVEE, POUVANT ETRE FORME A FROID,  
PROCEDE POUR PRODUIRE UN FEUILLARD D'ACIER ET UTILISATIONS D'UN TEL ACIER

(54) HIGHLY STABLE, STEEL AND STEEL STRIPS OR STEEL SHEETS COLD-FORMED, METHOD FOR THE  
PRODUCTION OF STEEL STRIPS AND USES OF SAID STEEL

(57)

The invention relates to steel strips or steel sheets exhibiting good cold forming ability and increased stability, comprising a light steel, which contains (in wt. %) C:  $\leq 1.00$  %, Mn: 7.00-30.00 %, Al: 1.00-10.00 %, Si:  $> 2.50$  - 8.00 %, Al + Si:  $> 3.50$  - 12.00 %, B:  $> 0.00$  -  $< 0.01$  %, and optionally Ni:  $< 8.00$  %, Cu:  $< 3.00$  %, N:  $< 0.60$  %, Nb:  $< 0.30$  %, Ti:  $< 0.30$  %, V:  $< 0.30$  %, P:  $< 0.01$  %, the remainder being iron and unavoidable impurities.



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CA 2414138 A1 2002/12/02

(21) **2 414 138**

(12) **DEMANDE DE BREVET CANADIEN  
CANADIAN PATENT APPLICATION**

(13) **A1**

(86) Date de dépôt PCT/PCT Filing Date: 2002/06/13

(87) Date publication PCT/PCT Publication Date: 2002/12/02

(85) Entrée phase nationale/National Entry: 2002/12/02

(86) N° demande PCT/PCT Application No.: EP 2002/006480

(87) N° publication PCT/PCT Publication No.: 2002/101109

(30) Priorité/Priority: 2001/06/13 (101 28 544.2) DE

(51) Cl.Int.<sup>7</sup>/Int.Cl.<sup>7</sup> C22C 38/04, C22C 38/06, C21D 8/02

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(54) Titre : ACIER ET FEUILLARD OU TOLE D'ACIER A RESISTANCE TRES ELEVEE, POUVANT ETRE FORME A FROID, PROCEDE POUR PRODUIRE UN FEUILLARD D'ACIER ET UTILISATIONS D'UN TEL ACIER

(54) Title: HIGHLY STABLE, STEEL AND STEEL STRIPS OR STEEL SHEETS COLD-FORMED, METHOD FOR THE PRODUCTION OF STEEL STRIPS AND USES OF SAID STEEL

(57) Abrégé/Abstract:

The invention relates to steel strips or steel sheets exhibiting good cold forming ability and increased stability, comprising a light steel, which contains (in wt. %) C:  $\leq 1.00$  %, Mn: 7.0030.00 %, Al: 1.00 10.00 %, Si:  $> 2.50$  8.00 %, Al + Si:  $> 3.50$  12.00 %, B:  $> 0.00$  -  $< 0.01$  %, and optionally Ni:  $< 8.00$  %, Cu:  $< 3.00$  %, N:  $< 0.60$  %, Nb:  $< 0.30$  %, Ti:  $< 0.30$  %, V:  $< 0.30$  %, P:  $< 0.01$  %, the remainder being iron and unavoidable impurities.

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OPIC • CIPQ 191

OPIC



CIPO

10/539099

SI/cs 010329WO

JC17 Rec'd PCT/PTO 15 JUN 2005

May 14, 2002

ABSTRACT OF THE DISCLOSURE

A steel strip or sheet steel having good cold formability and high-strength is described, comprising a light steel having (in weight-percent) C:  $\leq 1.00$  %, Mn: 7.00 - 30.00 %, Al: 1.00 - 10.00 %, Si:  $> 2.50 - 8.00$  %, Al + Si:  $> 3.50 - 12.00$  %, B:  $> 0.00 - < 0.01$  %, as well as alternately Ni:  $< 8.00$  %, Cu:  $< 3.00$  %, N:  $< 0.60$  %, Nb:  $< 0.30$  %, Ti:  $< 0.30$  %, V:  $< 0.30$  %, P:  $< 0.01$  %, with the remainder iron and unavoidable impurities.

SI/cs 010329WO

May 14, 2002

**High-strength, cold formable steel and steel strip or sheet steel, method of producing steel strip, and uses of such a steel**

The present invention relates to an Fe-Mn-Al-Si light steel and steel strip or sheet steel having good cold formability and high strength. In addition, the present invention relates to a method of producing strips from such a steel and particularly suitable uses of such a steel.

A light steel used for producing car body parts and for low-temperature use is known from German Patent 197 27 759 C2. It contains, in addition to Fe, 10 % to 30 % Mn, 1 % to 8 % Al, and 1 % to 6 % Si, the sum of the contents of Al and Si not exceeding 12 %. In this known steel, the carbon content, if any, is in the impurity range.

In the light structural steel known from German Patent Application 199 00 199 A1, in contrast, carbon is provided as an optional alloy element. The known light steel has > 7 % to 27 % Mn, > 1 % to 10 % Al, > 0.7 % to 4 % Si, < 0.5 % C, < 10 % Cr, < 10 % Ni, and < 0.3 % Cu. Furthermore, the steel may contain N, V, Nb, Ti and P, the sum of these elements not to exceed 2 %.

The light steel known from European Patent Application 1 067 203 A1 also contains carbon, in a range from 0.001 to 1.6 %. In addition, this steel has, besides Fe, 6 - 30 % Mn, ≤ 6 % Al, ≤ 2.5 % Si, ≤ 10 % Cr, ≤ 10 % Ni, and ≤ 5 % Cu. In addition, the steel may contain V, Ti, Nb, B, Zr, and rare earths, the sum of their contents not exceeding

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3 %. The known steel may also contain P, Sn, Sb, and As, the sum of the contents of these elements not to be greater than 0.2 %.

It has been shown that steels having these types of compositions may only be hot and cold rolled with difficulties, in spite of the presence of carbon. Thus, instabilities or cracks are frequently seen at the strip edges, which makes the large-scale production of strips or sheets from such steels difficult in practice. Furthermore, the steels have very strong isotropic deformation behavior, which is expressed in a high  $\Delta r$  value. The further processing of the sheet steels produced according to the known method is also made more difficult due to the poor formability.

Well-formable steels having higher strengths are also necessary for the manufacture of components which are provided with teeth or comparable shaped elements. These components are typically gear parts provided with inner or outer teeth. These may be produced cost effectively and with high dimensional accuracy through flow forming.

A method for producing gear parts through flow forming is known from German Patent 197 24 661 C2. According to this known method, a blank is produced from a microalloyed, high-strength structural steel, which has a lower yield point of at least 500 N/mm<sup>2</sup>, from a sheet. This blank is then cold formed into the gear through flow forming. In the course of forming in the teeth, the sheet material is reformed up to the limit of its forming ability. Subsequently, a surface of the workpiece provided with

the teeth is hardened without heat deformation while essentially maintaining the temperature.

The object of the present invention is, proceeding from the related art described above, to provide a light steel and/or a steel strip or sheet steel produced therefrom having good formability and good strength which may also be easily produced at an industrial scale. In addition, a method of producing a steel strip or sheet steel and preferred uses for the steel are to be indicated.

This object is achieved by a light steel which has the following composition (in weight-percent):

C:	≤ 1.00 %
Mn:	7.00 - 30.00 %
Al:	1.00 - 10.00 %
Si:	> 2.50 - 8.00 %
Al + Si:	> 3.50 - 12.00 %
B:	> 0.00 - < 0.01 %
as well as alternately	
Ni:	< 8.00 %
Cu:	< 3.00 %
N:	< 0.60 %
Nb:	< 0.30 %
Ti:	< 0.30 %
V:	< 0.30 %
P:	< 0.01 %

The remainder is Fe and unavoidable impurities. The impurities include sulfur and oxygen in this case.

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Surprisingly, it has been shown that the targeted addition of boron leads to significant improvement of the properties and producibility in steels according to the present invention. Thus, the content of boron contained in the steel according to the present invention causes reduction of the yield point, through which the formability is significantly improved. The favorable influence of the alloy on the mechanical-technological properties of steel according to the present invention may be reinforced even further if the carbon content is 0.10 - 1.00 weight-percent, i.e., if at least 0.10 weight-percent carbon is detectable in the steel according to the present invention.

In this case, the presence of these elements results in a particularly good combination of mechanical and technological properties. Thus, steel according to the present invention and/or steel strip or sheet steel produced therefrom has a significantly lower  $\Delta r$  value than sheet steel known from the related art of the species discussed here.

In addition, cold-rolled steel strips and steel sheets having the composition according to the present invention are distinguished by comparatively low yield points, improved stretch formability at elevated hardening exponents ( $n$  value), elevated deep drawing quality ( $r$  value), and lower planar anisotropy ( $\Delta r$  value) as well as an elevated product of yield point and elongation. Thus, the tensile strength of steel strips and steel sheets according to the present invention is at least 680 MPa. The product of tensile strength and elongation is at least 41,000 MPa. The yield point of steel sheets and

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strips according to the present invention does not exceed 520 MPa. Simultaneously, steels according to the present invention, and/or sheets and strips produced therefrom, have an extraordinarily high uniform elongation of 20 % up to more than 45 %.  $n$  values of up to 0.7 are achieved.

As a result, in this way an especially good cold formable light steel strip or sheet steel is obtained which, due to its comparatively high strength and low density, is particularly suitable for the production of components for automobile bodies. The outstanding ratio of strength and weight also makes sheet steel produced according to the present invention suitable for the production of wheels for vehicles, in particular motor vehicles, for the production of internally or externally hydroformed components, for the production of high-strength engine parts, such as camshafts or piston rods, for the production of components, such as armor plates, intended for protecting against pulsed stresses, such as bombardment, and for protective elements which are intended in particular for protecting people against bombardment. In particular in the case of the latter application, the comparatively low weight of the sheet steel according to the present invention and simultaneously its high strength has a positive effect.

Sheet steels according to the present invention are additionally especially suitable for producing non-magnetic components if they have a purely austenitic microstructure.

Furthermore, it has been shown that the steels according to the present invention maintain their strength even at

especially low temperatures. As such, they are particularly suitable for producing components used in cryoengineering, such as containers or pipes for cryoengineering.

The positive effects of boron in the steel used according to the present invention may be achieved especially reliably if the boron content is 0.002 weight-percent to 0.01 weight-percent, particularly 0.003 to 0.008 weight-percent.

The C content, which lies in the range from 0.1 % to 1.0 %, also ensures improved producibility of sheet steel and steel strip according to the present invention. In steels according to the present invention, the formation of intermetallic phases is suppressed due to the presence of carbon. Cracks and instabilities in the strip edge region, which arise in steel strips produced from the known steels, are thus significantly reduced, the instabilities especially being reduced with increasing C content. A further improvement of the strip edge quality is achieved by adding boron. As a result, strip edge instabilities may be almost completely avoided through the combined addition of C and B.

Boron acts as a substitute for alloy element Mn in its effect on the mechanical-technological properties. Thus, it has been established that a steel having 20 % Mn and 0.003 % boron has a similar property profile to a steel which contains 25 % Mn, but no B. Therefore, light structural steels according to the present invention may have relatively low Mn contents and still have relatively high strengths. This leads to reduced alloying element

costs and makes production of a light steel used according to the present invention in smelting metallurgy easier.

In addition, the contents of C and B provided according to the present invention open up a wide spectrum of hot rolling parameters. Thus, it has been established that the characteristics of steels according to the present invention obtained if high hot rolling final temperatures and coiler temperatures are selected are essentially identical to those which are obtained at low hot rolling final temperatures and coiler temperatures. This insensitivity during hot strip production also favors easy producibility of sheet steels according to the present invention.

Due to their Si contents, which are restricted to above 2.50 weight-percent, preferably above 2.70 weight-percent, steel strips and steel sheets according to the present invention have improved cold formability in comparison to those light steel strips or sheets which have lower Si contents. The high content of Si is expressed in more uniform yield point and tensile strength values and in higher fracture elongation and uniform elongation values. In addition, Si in steels according to the present invention leads to higher  $r$  and  $n$  values and to isotropic implementation of the mechanical properties. The upper limit of the sum of the contents of Al and Si is 12 %, since a sum of the Al and Si contents exceeding this limit would produce the danger of embrittlement.

The steel strips and sheets according to the present invention are preferably produced through a method in which an input stock, such as slabs, thin slabs, or strip, made of a steel according to the present invention having the composition described above, is cast, the cast input stock is heated to  $\approx 1100\text{ }^{\circ}\text{C}$  or used directly at such a temperature, the preheated input stock is hot rolled to hot strip at a hot rolling final temperature of at least  $800\text{ }^{\circ}\text{C}$ , and the finish-rolled hot strip is coiled at a coiler temperature of  $450\text{ }^{\circ}\text{C}$  to  $700\text{ }^{\circ}\text{C}$ .

Because the hot strip is hot rolled at hot rolling final temperatures of at least  $800\text{ }^{\circ}\text{C}$  and coiled at lower temperatures according to the present invention, the positive effect of the carbon and, in particular, of the boron described is used to its full extent. Thus, boron and carbon produce higher tensile strength and yield point values in strips hot rolled in this range with fracture elongation values which are still acceptable. As the hot rolling final temperature increases, tensile strength and yield point are reduced, while the elongation values increase. Through variation of the hot rolling final temperatures within the scope provided by the present invention, the desired properties of the steel strip may be influenced easily and in a targeted way.

Material embrittlement is reliably avoided by restricting the coiler temperature to values of at most  $700\text{ }^{\circ}\text{C}$ . It has been shown that brittle phases form at higher coiler temperatures, which may, for example, cause material flaking and thus make further processing more difficult or even impossible.

Even hot strip produced according to the present invention is distinguished by good usage properties. If thinner sheets or strips are to be produced, the hot strip may be cold rolled to cold strip after the coiling, the cold rolling advantageously being performed at a reduction of 30 % to 75 %. The cold strip obtained is subsequently preferably subjected to annealing, the annealing temperatures to be between 600 °C and 1100 °C. The annealing may be performed in this case in the hood in the temperature range from 600 °C to 750 °C or continuously in the annealing furnace at temperatures from 750 °C to 1100 °C. Finally, it is favorable in regard to the cold formability and the surface formation to dress the cold strip in a final step.

A further, particularly advantageous use of steel according to the present invention, and/or steel strips and sheets produced therefrom, is the production of cold-formed components through flow forming. For this purpose, blanks are produced from the steel, which are then finished by flow forming. Due to its special property profile, steel according to the present invention, and/or sheet blanks produced therefrom, are particularly suitable for this purpose.

A microstructure which is purely austenitic or which comprises a mixture of ferrite and austenite with components of martensite may result in the steel according to the present invention as a function of the composition. The steels according to the present invention may therefore be formed significantly better. They compact significantly more strongly in the course of

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cold forming than the known high-strength microalloyed or multiphase steels used for production through flow forming. Thus, depending on the cold forming, component strengths in the range from 1400 N/mm<sup>2</sup> to 2200 N/mm<sup>2</sup> may be achieved. Additional hardening of the components produced after the cold forming may therefore be dispensed with. It also has a favorable effect in regard to the intended purpose, in particular for the production of toothed gear components, if the steels used according to the present invention for their production have their density reduced due to the high content of light elements, such as Si and Al.

If a steel composed and constituted according to the present invention is used, then heat treatment or surface hardening of the flow formed component may be dispensed with. The danger of distortion and scaling caused in the related art by these additional processing steps therefore no longer exists if a steel according to the present invention is used to produce toothed elements subjected to localized strong stress in use. Thus, the steel according to the present invention allows cost-effective production of light, heavy-duty, and dimensionally stable components through cold forming, in particular flow forming.

In the following, the present invention is described in more detail with reference to exemplary embodiments and comparative examples.

The compositions of four steels A, B, C, D, E are indicated in Table 1, steels A, B, and C corresponding to

the alloy provided according to the present invention, while steels D and E are the comparative examples.

Steel	C	Mn	Al	Si	B	Fe, impurities
A	0.5	15	3	3	0.003	remainder
B	0.5	20	3	3	0.003	remainder
C	-	20	3	3	0.003	remainder
D	-	14	3	3	-	remainder
E	-	19	3	3	-	remainder

Table 1

Steels A to E of the compositions concerned are melted and cast into slabs. Subsequently, the slabs are preheated to a temperature of 1150 °C. The preheated slabs are then hot rolled and subsequently coiled.

Respective hot rolling final temperatures ET and coiler temperatures HT, and the respective properties of tensile strength  $R_m$ , yield point  $R_e$ ,  $A_{50}$  elongation, uniform elongation  $A_{g1}$ , and n value of the hot strips obtained are indicated in Table 2.

Steel	ET [°C]	HT [°C]	$R_e$ [N/mm <sup>2</sup> ]	$R_m$ [N/mm <sup>2</sup> ]	$A_{50}$ [%]	$A_{g1}$ [%]	n
A	960	500	486	792	42	38	0.31
B	930	500	509	825	46	42	0.32
C	920	500	496	818	31	27	-
D	820	500	610	920	26	-	-
E	840	500	430	700	30	-	-

Table 2

Except for the strip produced from steel D, which is not according to the present invention, and which could not

be cold rolled, the hot strips obtained were subsequently cold rolled at a degree of deformation of approximately 65 % and continuously annealed at 950 °C. The mechanical properties of the cold rolled steel sheets obtained in this way are listed in Table 3.

Steel	$R_e$ [N/mm <sup>2</sup> ]	$R_m$ [N/mm <sup>2</sup> ]	$A_{50}$ [%]	$A_{g1}$ [%]	$n$	$r$	$\Delta r$
A	408	775	64	64	0.33	1.02	-0.1
B	411	785	61.1	61.1	0.33	1.0	-0.06
C	284	714	58	56.8	0.39	1.05	-0.17
D	not cold rollable						
E	382	744	52.5	50.3	0.32	0.82	-0.25

Table 3

It has been shown that the steel strips produced according to the present invention from steels A to C have outstanding cold formability. In this case, at high strength and high fracture elongation, they each have an distinct isotropic deformation behavior ( $r \sim 1$ ,  $\Delta r \sim 0$ ). Even in the steel strips produced from steel C according to the present invention, which is carbon-free but contains boron, have lower yield points, elevated fracture and uniform elongations, and isotropic forming behavior.

Therefore, all variants of sheet steels according to the present invention are especially suitable for the production of car body components, especially for the outer panels of an automobile body, of wheels for vehicles, in particular motor vehicles, of non-magnetic components, of containers used in cryoengineering, of internally or externally hydroformed components, of tubes

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which are particularly intended for the production of high-strength engine parts, such as camshafts or piston rods, of components intended for protection against pulsed stresses, such as bombardment, or protective elements, such as armor plates, or body armor for human or animal bodies. Heavy-duty gear parts, which are distinguished by low weight and good usage properties, without requiring additional heat treatment for this purpose, may also be produced from steel sheets according to the present invention.

SI/cs 010329WO

May 14, 2002

CLAIMS

1. A light steel, having good cold formability and high strength, with the following composition (in weight-percent):

C:  $\leq 1.00 \%$

Mn: 7.00 - 30.00 %

Al: 1.00 - 10.00 %

Si:  $> 2.50 - 8.00 \%$

Al + Si:  $> 3.50 - 12.00 \%$

B:  $> 0.00 - < 0.01 \%$

as well as alternately

Ni:  $< 8.00 \%$

Cu:  $< 3.00 \%$

N:  $< 0.60 \%$

Nb:  $< 0.30 \%$

Ti:  $< 0.30 \%$

V:  $< 0.30 \%$

P:  $< 0.01 \%$ ,

with the remainder iron and unavoidable impurities.

2. The light steel according to Claim 1, characterized in that the carbon content is 0.10 - 1.00 weight-percent.
3. The light steel according to one of the preceding claims, characterized in that the Si content is  $> 2.70$  weight-percent.
4. The light steel according to one of the preceding claims, characterized in that the

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boron content is 0.002 weight-percent to 0.01 weight-percent, in particular 0.003 to 0.008 weight-percent.

5. A steel strip or sheet steel produced from a steel having a composition according to one of Claims 1 to 4.
6. The steel strip or sheet steel according to Claim 5, characterized in that its tensile strength is at least 680 MPa.
7. The steel strip or sheet steel according to Claim 5 or 6, characterized in that the product of its tensile strength and its elongation is at least 41,000 MPa.
8. The steel strip or sheet steel according to one of Claims 4 to 7, characterized in that its yield point is up to 520 MPa.
9. A method for producing a cold formable, high-strength steel strip or sheet steel, wherein
  - an input stock, such as slabs, thin slabs, or strip, is cast from a steel having a composition according to one of Claims 1 to 4,
  - the cast input stock is heated to  $\approx 1100$  °C or used directly at such a temperature,
  - the preheated input stock is hot rolled to hot strip at a hot rolling final temperature of at least 800 °C, and

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- the finish-rolled hot strip is coiled at a coiler temperature of 450 °C to 700 °C.

10. The method according to Claim 9,  
c h a r a c t e r i z e d i n t h a t t h e h o t s t r i p i s  
cold rolled to cold strip after the coiling.
11. The method according to Claim 10,  
c h a r a c t e r i z e d i n t h a t t h e c o l d s t r i p  
is subjected to annealing at an annealing  
temperature of 600 °C to 1100 °C.
12. The method according to Claim 11,  
c h a r a c t e r i z e d i n t h a t t h e a n n e a l i n g i s  
performed as hood annealing at an annealing  
temperature from 600 °C to 750 °C.
13. The method according to Claim 11,  
c h a r a c t e r i z e d i n t h a t t h e a n n e a l i n g i s  
performed as continuous annealing at an annealing  
temperature of 750 °C to 1100 °C.
14. The method according to one of Claims 10 to 13,  
c h a r a c t e r i z e d i n t h a t t h e c o l d s t r i p  
is dressed.
15. The method according to one of Claims 9 to 14,  
c h a r a c t e r i z e d i n t h a t t h e c o l d r o l l i n g  
is performed at a cold rolling reduction of 30 % to  
75 %.
16. The method according to one of Claims 9 to 15,  
c h a r a c t e r i z e d i n t h a t b l a n k s , w h i c h

are subsequently cold formed into finished components, are produced from the respective hot or cold strip obtained.

17. The method according to Claim 16, characterized in that the cold forming is performed as flow forming.
18. A use of a steel or a steel strip or sheet steel according to one of Claims 1 to 8 for producing supporting vehicle body components.
19. A use of a steel or a steel strip or sheet steel according to one of Claims 1 to 8 for producing externally visible parts of vehicle bodies.
20. A use of a steel or a steel strip or sheet steel according to one of Claims 1 to 8 for producing wheels for vehicles, in particular motor vehicles.
21. A use of a steel or a steel strip or sheet steel according to one of Claims 1 to 8 for producing non-magnetic components.
22. A use of a steel or a steel strip or sheet steel according to one of Claims 1 to 8 for producing components used in cryoengineering.
23. A use of a steel or a steel strip or sheet steel according to one of Claims 1 to 8 for producing internally or externally hydroformed components.

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24. A use of a steel or a steel strip or sheet steel according to one of Claims 1 to 7 for producing tubes, which are particularly intended for the production of high-strength engine parts, such as camshafts or piston rods.
25. A use of a steel or a steel strip or sheet steel according to one of Claims 1 to 8 for producing components, such as armor plates, intended for protection against pulsed stresses, such as bombardment.
26. A use of a steel or a steel strip or sheet steel according to one of Claims 1 to 8 for producing protection components, such as helmets and body armor, intended for protection of persons against pulsed stresses, such as bombardment.
27. A use of a steel or a steel strip or sheet steel according to one of Claims 1 to 8 for producing components through flow forming.
28. A use of a steel or a steel strip or sheet steel according to one of Claims 1 to 8 for producing gear parts.
29. The use according to Claim 28,  
c h a r a c t e r i z e d i n t h a t the gear parts  
are provided with teeth.
30. The use according to Claim 28 or 29,  
c h a r a c t e r i z e d i n t h a t the gear parts  
are produced through flow forming.